

1999

Cavitation in valves

Kevin Simon Boddéus
University of Wollongong

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CAVITATION IN VALVES

A thesis submitted in fulfilment of the
requirements for the award of the degree

DOCTOR OF PHILOSOPHY
IN ENGINEERING

from the

UNIVERSITY OF WOLLONGONG

by

Kevin Simon Boddéus BE(Hons), ME(Hons)

Volume 1

DEPARTMENT OF MECHANICAL ENGINEERING

1999

DECLARATION

This is to certify that the work presented in this thesis was carried out by the author in the Department of Mechanical Engineering at the University of Wollongong and has not been submitted for a degree to any other university or institution.

Kevin/Simon Boddeus

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Abstract

Cavitation is a phenomenon that is manifest in a wide variety of liquid flow situations. Of particular relevance to this thesis is its appearance in industrial pumps and valves. Much of the early work proceeded in the form of fundamental research. The mathematical formulae coupled with and shaped by the experimental work done in cavitation laboratories established the foundations of this subject. In the early twentieth century, the relevance of this fundamental research to industrial problem areas such as short-lived valves and pumps was realised. Driven by the commercial advantage of providing cavitation resistant products, various companies established, within their existing research and development departments, sections which examined the impacts of and solutions to cavitation. Using the fundamental research as a springboard for their own, these industrial engineers undertook extensive laboratory and field test work. From this they developed products and the formulae and rules of thumb that enabled them to scale-up (or scale-down) these products to suit various industrial applications. Much of the knowledge produced by these companies remains private.

The situation at present shows a marked divergence in these two areas of research. However, this thesis contends that the current climate in academia and industry, where co-operative research projects in other fields of interest set a precedent, is well suited to the establishment of a combined effort in the area of cavitation. The establishment of such co-operative research is complex and varied when considered against the background of the many institutions, companies, products and test equipment involved. The approach adopted by the author has been to examine the history and current state of the two avenues of research (fundamental and industrial) with a view to establishing the broader bases for the seeding of links between them. This has been done by examining some examples in industry that display the nature of the problem that cavitation poses together with some of the solutions, which are often only means of mitigating the effects of cavitation. Some general test work with both venturis and multiple orifice plate test rigs is presented where the problems associated with cavitation are discussed.

The terms of this examination have included a study of the products of industry as well as the basic experimental research tools adopted within institutions (orifice plate and venturi test rigs). It has been shown that there are grounds for work with such test rigs to develop industrial products whilst simultaneously leading to the furthering of our understanding of cavitation. Some phenomena (such as out of sequence, interstage cavitation) were discovered during testing that would lead to a re-examination of the mathematics currently being applied.

Within this thesis the author has developed a technique for examining the cavitation signatures of test items. This has been done by using a unique combination of tools such as high speed photography, image analysis and signal analysis software. This work is supplemented by a detailed study of multiple plate orifice arrays. The author presents means of overcoming the subjective nature of determining the points of incipient and desinent cavitation that have plagued researchers in the past. Finally, more detailed work, arising out of the practical need to protect valves and pumps from cavitation in severe service duties, has led to a method for designing multiple orifice plate arrays.

In addition to this, the author presents the concept for a device that performs high pressure liquid letdown (as used in large power stations) without suffering cavitation.

The over-riding conclusion of this thesis is that whilst there is significant ground for the establishment of common efforts in cavitation research, there is both much merit in and momentum for continuing the current divergent streams. The development of the common ground, however, acts to enrich both the public knowledge domain and accelerate the development of solutions to industrial cavitation.

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Nomenclature

symbol	description	units
a	average amplitude	m
a_f	amplitude of low frequency fluctuation component	m
A	Venturi cross sectional area	m ²
A_u	Venturi cross sectional area at throat exit	m ²
c	velocity of sound in liquid	m.s ⁻¹
c_g	velocity of sound in gas	m.s ⁻¹
C	. concentration of dissolved gases in the liquid	mol ratio
	. coefficient of discharge	-
C_R	overall coefficient of recovery of velocity pressure	
	measured from the cavitation zone to the resorber	-
C_S	saturation concentration of the dissolved gases in the liquid	mol ratio
d	diameter of orifice	m
d_b	bubble diameter	mm
D	upstream internal pipe diameter	m
f	frequency	Hz
f_b	bubble natural frequency	Hz
f_{cav}	cavitation cloud natural frequency	Hz
f_f	frequency of low frequency component	Hz
f_{liq}	natural frequency of liquid portion of venturi loop	Hz
h'	small pressure oscillation	Pa

symbol	description	units
H	cavitation cloud pressure in terms of hydraulic head	m
H	Henry's law coefficient	m ⁻¹
\overline{H}	average cavitation cloud pressure in terms of hydraulic head	m
k	uniform equivalent roughness	m
k_L	liquid film coefficient	m.s ⁻¹
L_{cav}	cavitation cloud length	m
L_n	n th pipe length	m
m	number of venturi loop pipes in series	-
p	pressure in the liquid	Pa
p_g	pressure of the gas in the bubble	Pa
p_g	gas partial pressure	Pa
p_t	threshold pressure for cavitation inception	Pa
p_v	vapour partial pressure	Pa
p_∞	pressure in the liquid	Pa
P	cavitation cloud pressure; pressure at the bubble wall	Pa
P_1	upstream pressure	Pa
P_2	downstream pressure	Pa
P_L	liquid pressure	Pa
P_r	downstream reference pressure	Pa
P_{sat}	saturation pressure	Pa
P_v	vapour pressure	Pa
\dot{q}	small flowrate oscillation	m ³ .s ⁻¹

Nomenclature

symbol	description	units
q_m	mass rate of flow	kg.s^{-1}
q_v	volume rate of flow	$\text{m}^3.\text{s}^{-1}$
Q	volume flowrate	$\text{m}^3.\text{s}^{-1}$
\overline{Q}	average flowrate	$\text{m}^3.\text{s}^{-1}$
R	bubble radius	m
\acute{R}	critical radius for nucleation	m
R_1	radius of a bubble as it enters the resorber	m
R_c	radius of the ring of contact between the interface and the wall of the crevice	m
Re	Reynold’s number	-
S_{cav}	wave propagation speed in cavitation cloud	m.s^{-1}
S_g	wave propagation speed in gas-liquid mixture	m.s^{-1}
$S_{liq\ n}$	wave propagation speed in liquid for n th pipe	m.s^{-1}
S_v	wave propagation speed in vapour-liquid mixture	m.s^{-1}
t	time variable	s
T	water temperature	°C
T_L	liquid temperature	°C
v	velocity in venturi throat	m.s^{-1}
V	velocity	m.s^{-1}
x	venturi longitudinal coordinate	m
x_d	coordinate value of cavitation cloud downstream interface	m
x_u	coordinate value of cavitation cloud upstream interface	m

Nomenclature

symbol	description	units
α	gas concentration (volume)	-
β	. crevice half angle	radians
	. diameter ratio $\beta = \frac{d}{D}$	-
γ	. ratio of specific heats	-
	. specific density of water	-
Δp	differential pressure	Pa
$\Delta \varpi$	pressure loss	Pa
μ	dynamic viscosity of the fluid	Pa.s
ν	kinematic viscosity of the fluid	$\text{m}^2.\text{s}^{-1}$
ρ	density	$\text{kg}.\text{m}^{-3}$
ρ_{cav}	cavitation cloud density	$\text{kg}.\text{m}^{-3}$
ρ_{gl}	gas-liquid mixture density	$\text{kg}.\text{m}^{-3}$
σ	cavitation number; surface tension	-
σ_{inc}	cavitation number for inception point	-
σ_{res}	cavitation number for cavitation resonance	-